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Description**Background of the Invention**

5 This invention relates to a cordierite body of low thermal expansion and high porosity. The invention relates to a method of making the body which makes use of a raw material composition of coarse talc in combination with silica, an alumina yielding component, and optionally, clay. More particularly, the body is formed by extrusion. Still more particularly, the body has a honeycomb structure.

Cordierite bodies having honeycomb structures are especially suited for but not limited to use as diesel
10 particulate filters and as substrates for catalysts and catalyst supports in converting automotive exhaust.

Honeycombs, especially extruded honeycombs, find use in a number of applications, such as diesel particulate filters, as substrates for catalytically active components for catalytic converters for automobiles, etc. Use of cordierite is favorable in these applications because of its good thermal shock resistance. The thermal shock resistance is inversely proportional to the coefficient of thermal expansion (CTE). That is,
15 honeycombs with low thermal expansion have good thermal shock resistance and can survive the wide temperature fluctuations that are encountered in the application.

In these particular applications, in addition to low thermal expansion, a high porosity is desirable. When the body is used as a diesel particulate filter, a high volume fraction of interconnected porosity enhances the filtration capacity of the filter. When the body is used as a substrate for catalysts in a catalytic
20 converter, a high porosity affords area for better adherence of high surface area washcoats which support the catalysts.

The following patents each relate to ceramic honeycombs having relatively low CTE's and various ranges of and types of porosity.

U.S. Patent 4,869,944 relates to a cordierite honeycomb structural body to be used as a catalyst carrier
25 having a low expansion ($\leq 3 \times 10^{-7} \cdot \text{C}^{-1}$ from 40 to 800 °C) with limited porosity in the range of $\geq 30\%$ and $< 42\%$.

European Patent Publication No. 0 354 721 relates to a porous ceramic honeycomb filter used as a diesel particulate filter. Cordierite is given as the the main component. The porosity is $> 42\%$. The thermal expansions are reported to be $\geq 7 \times 10^{-7} \cdot \text{C}^{-1}$ from 40 to 800 °C.

30 U.S. Patent 3,885,977 relates to an extruded honeycomb monolithic fired ceramic whose primary crystalline phase is cordierite and whose microstructure is characterized by a greater than random orientation of the anisotropic cordierite crystallites with their low thermal expansion direction aligned substantially parallel to the plane of the webs of the monolith. The axial expansion coefficient of the honeycomb with the composition near that of stoichiometric cordierite may be as low as $5.5 \times 10^{-7} \cdot \text{C}^{-1}$ or
35 lower in the range of 25 °-1000 °C. Porosity values are not disclosed.

It would be desirable and an advancement in the art to be able to produce a cordierite body which has a lower thermal expansion than has been set forth by the prior patents and at the same time has a high porosity.

SUMMARY OF THE INVENTION

In accordance with one aspect of the invention, there is provided a body of at least about 93% by weight cordierite, having a coefficient of thermal expansion of no greater than $4 \times 10^{-7} \cdot \text{C}^{-1}$, from 25 °C to 800 °C, and a total porosity of greater than 42%.

45 In accordance with another aspect of the invention, there is provided a method for producing the above described body which comprises selecting raw materials to form a composition which forms cordierite on firing, the raw materials being composed of: talc having a BET surface area of no greater than 5 m²/g, 0 to 48% by weight of clay, which can be platelet clay, stacked clay which can be delaminated into platelets during processing, and mixtures thereof, an aluminum oxide yielding component having an average particle
50 size of either 3 to 8 micrometers in diameter, or no greater than 3 micrometers in diameter, and free silica, intimately blending the raw materials with an effective amount of vehicle and forming aids to impart plastic formability and green strength to the raw materials and form a plastic mixture therefrom. If the particle size of the aluminum oxide yielding component is no greater than 3 micrometers in diameter, the raw materials are blended additionally with a burnout agent. The raw materials are formed into a green body which is
55 dried and fired at a sufficient temperature for a sufficient time to form the cordierite body.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 is a plot of % filtration efficiency versus % porosity >10 micrometers for bodies of the present invention as used as diesel particulate filters.

Figure 2 is a plot of pressure drop versus % porosity >10 micrometers for bodies of the present invention as used as diesel particulate filters.

DETAILED DESCRIPTION OF THE INVENTION

This invention relates to a cordierite body of low thermal expansion and high porosity and to the method of making the body. The low thermal expansion enhances the life of the body through repeated very high-very low temperature fluctuations that may be encountered in the application. The body is especially suited for, although not limited to, use as a diesel particulate filter. In this application, the high porosity allows for increased filtering capacity. Moreover, various combinations of pore sizes can be attained in the high porosity body while the very low CTE is maintained. Thus, the body can be made to suit a variety of applications, e.g., a variety of filtering applications. In accordance with another contemplated use, the relatively high porosity allows a higher surface area for increased loading of catalytic components when the body is used as a catalytic converter, or for better coatability for other end use applications.

Description of the Raw Materials and Composition

The raw materials are selected to form a composition of MgO, Al₂O₃, and SiO₂ which will form cordierite on firing. The composition preferably consists essentially of nominally, in percent by weight 12 to 16 magnesium oxide, 33 to 38 aluminum oxide, and 49 to 54 silica. The most preferred composition consists essentially of nominally in percent by weight 12.5 to 15.5 magnesium oxide, 33.5 to 37.5 aluminum oxide, and 49.5 to 53.5 silica.

Although the composition is relatively pure, some allowance is made for impurities. Impurities within the cordierite body are of concern since these can affect properties such as increasing CTE. Typically cordierite bodies are affected by impurities such as CaO, K₂O, Na₂O, Fe₂O₃, etc. It is desirable that the sum of the CaO, K₂O, and Na₂O content be no greater than 0.15% by weight based on the total raw materials.

The Type of Talc

One of the critical features of the present invention is the form of talc. All or part of the talc can be calcined.

The talc is provided in the form of coarse talc. By coarse talc is meant that it must have a BET surface area of no greater than 5 m²/g, and preferably no greater than 3 m²/g. It is preferred that the talc be platy. By platy talc is meant a platelet particle morphology, that is, the particles have two long dimensions and one short dimension, or, the length and width of the platelet are much larger than its thickness. It is preferred that the talc have a morphology index of no less than about 0.80. The morphology index is a measure of the degree of platiness of the talc. One typical procedure for measuring the morphology index is to place the talc sample in a holder so that the orientation of the platy talc is maximized within the plane of the sample holder. The x-ray diffraction pattern is then determined for this oriented talc. The morphology index semiquantitatively relates the platy character of the talc to its XRD peak intensities using the following equation:

$$M = I_x(I_x + 2I_y)^{-1}$$

where I_x is the intensity of the (004) peak and I_y is that of the (020) reflection [overlapped with the (111-) and (110)]. It is also preferred that the quotient of the talc mass percent <2 micrometers in diameter/the talc morphology index be no greater than 30 and preferably no greater than 20. Calcium is normally present as an impurity in talc. In accordance with the present invention, CaO is preferably no greater than 0.3% and most preferably no greater than 0.15% by weight in the talc.

The Type of Clay

In accordance with the present invention, clay can be present as part of the raw material composition. When clay is present, it makes up no greater than 48% and preferably no greater than 20% by weight of the raw material composition. When clay is used as a raw material, it must have specific properties in order to attain the low CTE-high porosity combination in the body. The clay is provided in the form of a platelet clay which has platelet dimensions as described above for the talc, or stacked clay which can be delaminated into platelets during processing, or mixtures thereof. The mineral kaolinite occurs in "stacks" of platelets with one platelet stacked on top of others like slices in a loaf of bread. The stack of platelets forms a rod shaped grouping within the length of the stack substantially larger than the diameter. These kaolin stacks are then broken apart (delaminated) by mechanical processing and the individual platelets are separated. Now each platelet has a diameter (or length and width) significantly larger, e.g., ten times larger than its thickness. It is preferred that the BET surface area of the clay be no less than 7 m²/g, and most preferably no less than 10 m²/g based on clay in the uncalcined state. This means that if clay is to be calcined prior to use in the raw material composition of the present invention, the BET surface area before calcining must be preferably no less than 7 m²/g and most preferably no less than 10 m²/g. The preferred types of clay are kaolin, calcined clay and combinations of these. If calcined clay is used as part or all of the clay component, the weight percent mullite in the calcined clay is no less than 2% of the total mass of the calcined clay. The weight percent mullite that can potentially form after complete recrystallization of the clay by prolonged calcination at high temperatures is 65% of the mass of the calcined clay.

The Type of Aluminum Oxide Yielding Component

The aluminum oxide yielding component can be aluminum oxide per se, or any material that when fired forms aluminum oxide. The aluminum oxide yielding component must be of fine particle size in order for the low CTE to be attained in the body. The average particle size of the aluminum oxide yielding component is no greater than 8 micrometers in diameter. The aluminum oxide yielding component can have an average particle size of either from 3 to 8 micrometers in diameter, or no greater than 3 micrometers in diameter. When the average particle size of the aluminum oxide yielding component is no greater than 3 micrometers in diameter, the addition of a burnout agent is necessary to maintain a total porosity of greater than 42% by volume. Some preferred aluminum oxide yielding components that are especially suited to the practice of the present invention are aluminum oxide, aluminum hydroxide, aluminum oxyhydrate, and combinations of these. It is preferred to have aluminum hydroxide at a level of no less than 1% by weight and most preferably no less than 5% by weight of the raw materials. Some preferred aluminum oxide yielding components are alumina, and a combination of alumina and aluminum hydroxide. In these combinations and other combinations, the alumina is preferably alpha alumina.

The Type of Free Silica

The silica can be provided in any available form, e.g., crystalline, amorphous, etc.

The raw materials of the present invention result in the formation of cordierite in the subsequent firing step.

A burnout agent or agents can be added to enable further control of the porosity to desired levels as discussed previously. A burnout agent is any particulate substance (not a binder) that burns out of the green body in the firing step. When the aluminum oxide yielding component has a very fine particle size, that is, an average no greater than 3 micrometers in diameter, a burnout agent is necessary to achieve a total porosity of greater than 42% in the body. If the average particle size of the aluminum oxide yielding component is about 3 to 8 micrometers in diameter, a burnout agent can be used to further increase the porosity. Some types of burnout agents that can be used, although it is to be understood that the invention is not limited to these, are organics that are solid at room temperature, elemental carbon, combinations of these, etc., for example, graphite, cellulose, flour, etc. Elemental carbon is preferred. Graphite is especially preferred because it has the least adverse effect on the processing. In an extrusion process, for example, the rheology of the extrudable mixture is good when graphite is used. Graphite has a consistent particle size. Therefore consistent results as far as porosity can be attained. With graphite, the formed body dries without cracking. The BET surface area of the graphite is preferably no greater than 5 m²/g in order to maintain a high degree of orientation in the cordierite, and microcracking.

The above composition is then blended with a vehicle and forming aids which impart plastic formability and green strength to the raw materials when they are shaped into a body. When the forming is done by

extrusion, the extrusion aids most typically used are methyl cellulose which serves as a binder, and a lubricant such as sodium stearate, although the invention is not limited to these.

The relative amounts of forming aids can vary depending on factors such as nature and amounts of raw materials used, etc. Typically, however, when methyl cellulose is used, it is present at a level of 1% to 6% as a super addition to the raw materials. Typically, when sodium stearate is used as the lubricant, it is present at a level of up to 1% by weight as a super addition to the raw materials. Some especially preferred vehicle/forming aid combinations will be described in the examples that follow.

In accordance with a preferred embodiment, for an extrusion process, the raw material composition and extrusion aids are mixed together in dry form and then mixed with water as the vehicle. The amount of water can vary from one batch of materials to another and therefore is determined by pre-testing the particular batch for extrudability.

The raw materials in the resulting plastic mixture are then formed into a green body. Articles which are unsintered are referred to as green bodies. Extrusion techniques are well known in the art. Some examples of preferred techniques will be given in the examples that follow for fabrication of the preferred types of bodies.

The invention is not limited to shape and size of the body. The body can have any shape and size depending on the application. One preferred structure is a honeycomb structure. Some examples of honeycomb structures, are those having about 94 cells/cm² (about 600 cells/in²), about 62 cells/cm² (about 400 cells/in²), or about 47 cells/cm² (about 300 cells/in²), those having about 31 cells/cm² (about 200 cells/in²), or those having about 15 cells/cm² (about 100 cells/in²). Honeycombs having about 15 to about 30 cells/cm², (about 100 to about 200 cells/in²) and about 0.30 to about 0.64 mm (about 12 to about 25 mil) wall thicknesses are especially suited for diesel particulate filter applications.

Once the green body is formed, it is dried at a temperature sufficient to remove any water or liquid phases that might be present.

It is then fired at a sufficient temperature for a sufficient time to form a cordierite body. The firing conditions can vary depending on the process conditions such as specific composition, size of the charge, and nature of the equipment. However, some preferred firing conditions are as follows:

heating the green body to a first temperature of 1100°C to 1150°C, and thereafter from the first temperature to a second temperature of 1300°C to 1350°C at a firing rate of 5°C to 100°C per hour, and preferably 20°C to about 100°C per hour, and thereafter to a third temperature of at least 1390°C, most typically 1390°C to 1430°C, and preferably 1400 to 1410°C and holding at the third temperature for 6 hours to 16 hours.

The bodies of the present invention are at least 93% by weight cordierite. Other phases such as for example, mullite, spinel, etc. can be present. However, these phases are present only to the extent that they do not raise the CTE of the body above $4 \times 10^{-7} \text{ }^{\circ}\text{C}^{-1}$, from 25°C to 800°C. (All CTE values are for 25°C to 800°C). Preferably, the bodies are at least 97% by weight cordierite.

The cordierite bodies of the present invention are characterized by a low CTE, that is, a CTE of less than $4 \times 10^{-7} \text{ }^{\circ}\text{C}^{-1}$ at 25°C to 800°C and most advantageously no greater than $2 \times 10^{-7} \text{ }^{\circ}\text{C}^{-1}$ at 25°C to 800°C. The bodies of the present invention are additionally characterized by a relatively high porosity, that is, a total porosity of greater than 42% by volume. The upper limit of porosity is determined by practical considerations. However, the total porosity is most typically 42% to 60% by volume.

The bodies of the present invention most advantageously have a median pore diameter of 5 to 40 micrometers especially for diesel particulate filter applications.

Most advantageously, in 30% to 100% of the total porosity the pore diameter is greater than about 10 micrometers for diesel particulate filter applications.

The body, when formed as a honeycomb structure for example, by extrusion, is further characterized by the I ratio. The I ratio is represented by the formula:

$$\text{I ratio} = \frac{I_{(110)}}{I_{(110)} + I_{(002)}}$$

where $I_{(110)}$ and $I_{(002)}$ are the peak heights of the reflections from the (110) and (002) planes respectively, based on hexagonal cordierite crystal structure. The axial and transverse I ratio refer to different orientations of a honeycomb sample in the x-ray beam. The x-ray beam impinges a planar surface at an angle. Measurements of the transverse I ratio are made when the planar surface of the sample is the flat surface

made up of as formed wall surfaces of the honeycomb. Measurements of the axial I ratio are made off a plane which is perpendicular to the length of the cell channels (and, therefore, also perpendicular to that for a transverse I ratio) where the planar surface on which the x-rays impinge consists of the cross-sectional ends of the honeycomb webs. For a completely randomly oriented cordierite, the I ratio will be 0.65. If the I ratio measured in the transverse direction with respect to the extrusion direction of the body exceeds 0.69 or the axial I ratio with respect to the extrusion direction is less than 0.61, then the cordierite crystallites are becoming substantially oriented with respect to the plane of the webs. The bodies of the present invention typically have a transverse I ratio of greater than about 0.69, and an axial I ratio of less than about 0.61.

It is well established that the coefficient of thermal expansion of cordierite cellular bodies in the axial direction (parallel to the cell channels), α_{ax} , is affected by non-random crystallographic orientation of the cordierite crystals in the microstructure, by the degree of microcracking present in the body after firing, and by the presence of high-expansion extraneous phases.

Specifically, a high volume fraction of cordierite crystals having their crystallographic z-axes oriented so as to lie near the plane of the cell walls (webs) reduces α_{ax} because the thermal expansion coefficient of cordierite is lowest (actually negative below about 1100 °C) along the direction of the z-axes. The degree of net preferred orientation of cordierite in the ceramic body is conventionally expressed by the value of the "transverse I-ratio," abbreviated "I_t." An increase in I_t produces a decrease in α_{ax} due to a greater contribution of low-expansion z-axes to α_{ax} within the plane of the web.

Microcracking has also been shown to significantly reduce α_{ax} in cordierite ceramics. Microcracking occurs during cooling as a result of stresses generated throughout the microstructure due to the high anisotropy in the thermal expansion (contraction) coefficient of cordierite along its three crystallographic axes. It has been observed that the cordierite crystals exist in fan-like "domains" of radially aligned crystals. Cordierite crystals within a given domain are subparallel to one another, so that the entire domain exhibits the same high degree of thermal expansion (contraction) anisotropy as the cordierite crystals of which it is comprised.

Because the z-axes of cordierite crystals in one domain will typically be oriented in a different direction from the z-axes of the crystals in the adjacent domains, high thermal stresses are generated throughout the web during cooling, producing microcracks. Upon reheating, thermal expansion of the domains is partially accommodated by the re-closing of these cracks, so that the thermal expansion of the bulk ceramic is lower than would be the case in an unmicrocracked body. Furthermore, it has been shown that the degree to which microcracking lowers α_{ax} is proportional to the mean size of the domains that comprise the ceramic microstructure.

To more fully illustrate the invention, the following non-limiting examples are presented. All parts, portions, and percentages are by weight unless otherwise stated.

General Procedure

The combinations of talc, calcined talc, kaolin, aluminum oxide, aluminum hydroxide, quartz, fused silica, graphite, and cellulose fiber shown in Tables 1 and 2 are blended together with 2 to 4 parts of methyl cellulose and 0.5 to 0.75 parts of sodium stearate. The particle profiles of the raw materials are shown in Tables 3 and 4, and their chemistries are shown in Table 5.

Subsequently about 23 to 26 parts of deionized water are gradually added to each powder mixture in a muller. After kneading, the combined ingredients are transferred to a vacuum extruder and extruded through a die into 2.54 cm diameter honeycomb bodies having approximately 0.425 millimeter thick walls and approximately 15.5 square shaped cells (channels) per square centimeter. The bodies thus formed are cut into approximately 30 centimeter long samples and heated until dried.

After drying, the extruded honeycombs are cut into shorter lengths and heated over a 60 hour period to a temperature of 1400 °C and held for 7 hours. The fired honeycombs are then cut into smaller specimens for physical property measurement and characterization of secondary phases. The thermal expansion coefficient is measured along the direction parallel to the length of the open channels of the honeycomb, herein referred to as the axial direction. Thermal expansion coefficients reported in Tables 1 and 2 are the average values over the range 25 to 800 °C. The transverse I ratio, I_t, is determined by x-ray diffractometry of the as-fired surfaces of the cell walls, as discussed previously. Volume percent porosity and median pore size are determined from mercury intrusion porosimetry. Quantitative measurement of the weight percent of mullite and spinel in the fired honeycombs is performed by powder x-ray diffractometry. The weight percent of cordierite is calculated by difference from 100 percent.

Inventive Examples

Compositions A through N in Table 1 demonstrate cordierite ceramics according to the present invention in which thermal expansion coefficient is no greater than $4 \times 10^{-7} \cdot \text{C}^{-1}$ and volume percent porosity is greater than 42%. The very low thermal expansion coefficients of $0.9 \times 10^{-7} \cdot \text{C}^{-1}$ and $1.2 \times 10^{-7} \cdot \text{C}^{-1}$ for compositions C and D demonstrate the further benefit of the very low calcium content of Talc 4 (Table 5).

Composition E demonstrates the further increase in percent porosity that is achieved by the super addition of 10 weight percent graphite to composition A.

Composition F shows that calcined talc can be present in the raw materials without adversely affecting the thermal expansion coefficient or porosity.

Compositions G through M demonstrate that a fine alumina powder can be utilized as a raw material, and, in such batches, the addition of a burnout agent is necessary in yielding at least 42 volume percent porosity in the fired body.

Compositions G through L further show that a very coarse crystalline silica (Silica 2, Table 4) can be used as raw material without adversely affecting the thermal expansion coefficient. Also, compositions K and L demonstrate that chopped cellulose fiber can be utilized as a burnout agent to maintain a porosity greater than 42 volume percent.

Finally, composition N demonstrates that thermal expansion coefficients no greater than $4 \times 10^{-7} \cdot \text{C}^{-1}$ are also attainable using coarser clay (Kaolin 2) as a raw material in place of finer clay (Kaolin 1). However, it is evident that the thermal expansion coefficient of the body made with the coarser clay is not as low as those of the bodies made with the finer clay. Therefore, a clay with a surface area greater than $7 \text{ m}^2/\text{g}$ is preferred.

In all of the inventive examples in Table 1, the cordierite transverse I-ratio ranges from 0.87 to 0.91, indicating a relatively high degree of preferred cordierite orientation with crystal z-axes preferentially oriented within the plane of the cell walls of the honeycomb ceramic. This high degree of orientation is attributed to the highly platy nature of the raw materials used in these examples.

Comparative Examples

Comparative examples of cordierite honeycomb ceramics having thermal expansion coefficients greater than $4 \times 10^{-7} \cdot \text{C}^{-1}$ are shown in Table 2. All of these samples are prepared according to the previously described general procedure.

Comparative compositions O through S demonstrate that the use of a talc raw material having a specific surface area in excess of $5 \text{ m}^2/\text{g}$ (Talc 1, Table 3) results in an increase in the thermal expansion coefficient to greater than $5 \times 10^{-7} \cdot \text{C}^{-1}$. Furthermore, the lower platiness of Talc 1, indicated by its lower Morphology Index (Table 3), produces a lower degree of preferred orientation of the cordierite in the fired bodies, as indicated by the lower transverse I ratios of 0.81 to 0.87 for compositions O through S in Table 2.

Comparative composition T in Table 2 shows that the use of a coarse talc and fine clay is insufficient to ensure a thermal expansion coefficient less than about $4 \times 10^{-7} \cdot \text{C}^{-1}$ when the composition in terms of the weight percentages of anhydrous end member oxides lies outside the range of the invention such that an inordinate amount of secondary phases are present after firing.

Finally, comparative example U, made with the same raw materials as inventive composition I, but fired at only 1385°C for about 7 hours, demonstrates the need to fire the bodies at a sufficiently high temperature to ensure that the amount of unreacted intermediate reaction products, such as spinel, does not exceed the limits required to maintain the thermal expansion coefficient less than $4 \times 10^{-7} \cdot \text{C}^{-1}$.

Diesel Particulate Filter Testing

Selected samples from Table 1 are plugged in alternating cells on one end and opposite alternating cells on the other end. The plugging compound utilized is a paste composed of pulverized, fired cordierite in an organic binder. Cells are plugged to a depth of 2.54 cm. The samples are then refired to 1390°C to cure the plugging "cement".

Samples are then tested on a diesel soot (aerosol) generator at a flow rate of $0.6 \text{ m}^3/\text{minute}$. Efficiency at a soot average particle size range of 0.3 to about 0.4 micrometers and pressure drop are determined, and are plotted against the volume percent porosity greater than about 10 micrometers in Figures 1 and 2 respectively. These data show that the inventive examples provide highly satisfactory filtration efficiencies of about 75% to about 95% at tolerable pressure drops of less than about 1000 mm of water, demonstrating

that these materials are suitable for diesel particulate filter applications.

TABLE 1
COMPOSITIONS AND PHYSICAL PROPERTIES FOR LOW THERMAL EXPANSION COEFFICIENT INVENTIVE EXAMPLES.

Batch Component Parts by Weight	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Talc 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Talc 2	39.9	-	-	-	39.9	30.3	40.7	40.7	40.7	40.7	40.7	40.7	39.9	39.9
Talc 3	-	39.9	-	-	-	-	-	-	-	-	-	-	-	-
Talc 4	-	-	39.9	40.7	-	-	-	-	-	-	-	-	-	-
Calcined Talc 2	-	-	-	-	-	9.9	-	-	-	-	-	-	-	-
Kaolin 1	16.6	16.6	16.6	16.0	16.6	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.6	-
Kaolin 2	-	-	-	-	-	-	-	-	-	-	-	-	-	16.6
Alumina 1	15.0	15.0	15.0	14.8	15.0	14.8	-	-	-	-	-	-	-	15.0
Alumina 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alumina 3	-	-	-	-	-	-	14.8	14.8	14.8	-	-	-	-	-
Aluminum Hydroxide 1	15.8	15.8	15.8	16.0	15.8	16.0	16.0	16.0	16.0	16.0	16.0	16.0	15.8	15.8
Silica 1	12.7	12.7	12.7	12.5	12.7	12.5	-	6.3	-	6.3	6.3	6.3	12.7	12.7
Silica 2	-	-	-	-	-	-	12.5	6.3	12.5	6.3	6.3	6.3	-	-
Burnout 1	-	-	-	-	-	-	15.0	-	-	-	-	-	-	-
Burnout 2	-	-	-	-	10.0	-	-	15.0	10.0	-	-	-	15.0	15.0
Burnout 3	-	-	-	-	-	-	-	-	-	-	2.0	10.0	-	-
Weight % MgO	13.7	13.7	13.7	14.1	13.7	14.1	14.1	14.1	14.1	14.1	14.1	14.1	13.7	13.7
Weight % Al ₂ O ₃	35.7	35.7	35.7	35.6	35.7	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.7	35.7
Weight % SiO ₂	50.6	50.6	50.6	50.3	50.6	50.3	50.3	50.3	50.3	50.3	50.3	50.3	50.6	50.6
Thermal Expansion Coefficient θ	2.7	3.4	0.9	1.2	3.4	2.5	1.9	3.9	3.8	1.4	2.8	1.5	2.4	4.0
Transverse I-ratio	-0.90	0.88	0.90	0.90	0.88	0.89	0.87	0.87	n.d.	0.89	0.90	0.88	0.90	0.91
Volume % Porosity	43.0	45.0	43.0	44.0	48.0	44.0	46.0	48.0	47.0	47.0	46.0	50.0	46.0	45.0
Median Pore Size (μ m)	9.1	15.4	12.3	12.0	11.0	8.8	19.0	28.0	24.6	14.0	13.1	12.4	9.0	10.0
% Porosity > 10 μ m	32.3	72.2	62.9	60.9	55.8	40.6	87.3	91.0	75.8	55.8	64.5	65.0	44.6	45.6
Weight % cordierite	96.7	96.9	97.5	98.6	96.3	98.0	98.5	99.0	98.0	97.8	98.0	98.7	98.2	96.7
Weight % spinel	2.6	2.0	1.6	1.4	2.8	2.0	1.5	1.0	2.0	1.7	2.0	1.3	1.8	2.4
Weight % mullite	0.7	1.1	0.9	0.0	0.9	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.9

- Not included

θ $10^{-7} \text{ } ^\circ\text{C}^{-1}$ (25°C to 800°C)

TABLE 2
COMPOSITIONS AND PHYSICAL PROPERTIES FOR COMPARATIVE EXAMPLES.

Batch Component Parts by Weight	O	P	Q	R	S	T	U ^a
Talc 1	39.9	39.9	39.9	39.9	39.9	39.9	40.7
Talc 2	-	-	-	-	-	-	-
Kaolin 1	16.6	16.6	16.6	16.6	16.6	16.6	16.0
Kaolin 2	-	-	-	-	-	-	-
Alumina 1	15.0	15.0	15.0	15.0	15.0	15.0	-
Alumina 2	-	-	-	-	-	15.8	-
Alumina 3	-	-	-	-	-	-	14.8
Aluminum Hydroxide 1	15.8	15.8	15.8	15.8	15.8	-	16.0
Silica 1	12.7	12.7	-	-	-	12.7	-
Silica 2	-	-	-	12.7	-	-	12.5
Silica 3	-	-	12.7	-	-	-	-
Silica 4	-	-	-	-	12.7	-	-
Burnout 1	15.0	-	15.0	15.0	15.0	-	-
Burnout 2	-	15.0	-	-	-	15.0	10.0
Weight % MgO	13.7	13.7	13.7	13.7	13.7	12.9	14.1
Weight % Al ₂ O ₃	35.7	35.7	35.7	35.7	35.7	39.5	35.6
Weight % SiO ₂	50.6	50.6	50.6	50.6	50.6	47.7	50.3
Thermal							
Expansion Coefficient ^b	6.1	7.4	5.1	7.0	6.2	7.0	7.3
Transverse I-ratio	0.84	0.84	0.87	0.85	0.81	0.89	-
Volume % Porosity	50.0	50.0	49.0	50.0	48.0	46.0	47.0
Median Pore Size (μm)	15.0	12.0	21.0	31.0	11.0	8.0	22.0
Weight % cordierite	97.0	96.8	97.9	95.3	97.5	88.6	94.5
Weight % spinel	2.2	2.5	2.1	4.0	2.5	4.2	5.0
Weight % mullite	0.8	0.7	0.0	0.7	0.0	7.2	0.5

^a Fired at 1385°C for 7 hours

^b Not included

^c 10⁻⁷°C⁻¹ (25°C to 800°C)

TABLE 3
PARTICLE PROFILES FOR SELECTED RAW MATERIALS

RAW MATERIAL	\bar{X} 20 μ	\bar{X} 10 μ	\bar{X} 5 μ	\bar{X} 2 μ	MPS ^g	SURFACE AREA ^a	MORPHOLOGY INDEX
Talc 1	81.5	66.0	51.0	30.0	5.0	6.8	0.65
Talc 2	81.5	56.5	32.0	11.5	8.0	2.1	0.94
Talc 3	71.0	50.0	32.5	14.5	10.0	2.2	0.95
Talc 4	83.0	63.0	39.0	15.0	7.0	1.7	0.95
Calcined Talc 2	84.0	55.0	30.0	8.0	9.0	1.2	platy
Kaolin 1	100.0	100.0	100.0	86.0	1.0	14.0	NA
Kaolin 2	95.0	75.0	41.0	8.0	8.0	7.0	NA
Alumina 1	98.0	90.0	59.0	5.0	4.5	1.0	NA
Alumina 2	100.0	100.0	98.0	96.0	0.5	10.0	NA
Alumina 3	100.0	98.0	84.0	33.0	3.0	2.5	NA
Aluminum Hydroxide 1	100.0	100.0	85.0	23.5	3.0	3.7	NA

^a MPS - Median particle size (μ m) from Sedigraph analysis
^b N₂ BET in units of m²/g
 NA Not applied
^c Calculated at 1200°C.

TABLE 4
PARTICLE PROFILES FOR SELECTED RAW MATERIALS (continued)

RAW MATERIAL	PERCENT FINER THAN			SURFACE AREA ^a
	90 μ	50 μ	10 μ	
Silica 1 ^b	50 μ	20 μ	3 μ	0.5
Silica 2 ^b	170 μ	100 μ	50 μ	0.3
Silica 3 ^b	107 μ	46 μ	8 μ	0.6
Silica 4 ^b	23 μ	7 μ	1 μ	5.0
Burnout 1 ^c	232 μ	101 μ	50 μ	1.3
Burnout 2 ^c	84 μ	39 μ	8 μ	4.3

^a N₂ BET in units of m²/g

^b Microtrac - Leeds & Northrup
^c Sieve analysis
 Silicas 1, 2, and 4 are alpha quartz.
 Silica 3 is fused silica.

TABLE 5
CHEMISTRIES OF SELECTED RAW MATERIALS (IN WEIGHT PERCENTS)

RAW MATERIAL	MgO	SiO ₂	Fe ₂ O ₃	CaO	Al ₂ O ₃	MnO	K ₂ O + Na ₂ O	LOI [†]
Talc 1	31.3	61.0	1.22	0.13	1.10	*	0.03	5.40
Talc 2	30.4	61.6	1.72	0.14	0.12	0.50	0.08	5.31
Talc 3	31.8	63.3	0.04	0.29	0.04	*	0.03	4.84
Talc 4	30.3	62.8	3.00	0.07	0.12	0.30	0.02	4.94
Calcined Talc 1	32.1	65.2	1.84	0.13	0.11	0.50	0.01	0.06
Keolin 1	*	45.1	0.34	0.02	38.5	*	0.15	14.2
Keolin 2	0.02	45.8	0.25	0.03	38.6	*	0.20	14.0
Alumina 1	*	0.03	*	*	99.4	*	0.30	0.29
Alumina 2	*	0.06	*	*	99.3	*	0.09	0.60
Alumina 3	*	0.02	0.01	*	99.7	*	0.08	0.15
Aluminum Hydroxide 1	*	*	*	*	65.0	*	0.24	34.7
Silica 1	*	99.8	*	*	*	*	*	0.21
Silica 2	*	99.8	*	*	*	*	*	0.21
Silica 3	*	99.9	*	*	*	*	*	0.05
Silica 4	*	99.5	*	*	*	*	*	0.52
Burnout 1	*	*	*	*	*	*	*	99.9
Burnout 2	*	*	*	*	*	*	*	99.9
Burnout 3	*	*	*	*	*	*	*	99.9

† LOI - Lost on ignition at 1000°C
* Not detected

Claims

1. A method for producing a cordierite body, said method comprising:
 - a) selecting raw materials to form a composition which forms cordierite on firing, said raw materials being composed of:
 - talc having a BET surface area of no greater than 5 m²/g,
 - 0 to 48% by weight of clay, said clay being selected from the group consisting of platelet clay, stacked clay which can be delaminated into platelets during processing, and mixtures thereof,
 - an aluminum oxide yielding component having an average particle size selected from the group consisting of 3 to 8 micrometers in diameter, and no greater than 3 micrometers in diameter, and free silica,
 - b) intimately blending said raw materials with an effective amount of vehicle and forming aids to impart plastic formability and green strength to said raw materials and form a plastic mixture therefrom, and with a burnout agent when said average particle size of said aluminum oxide yielding component is no greater than about 3 micrometers in diameter;
 - c) forming said raw materials into a green body;
 - d) drying said green body; and
 - e) heating said green body at a sufficient temperature for a sufficient time to form a cordierite body, wherein the cordierite body is at least 93% by weight cordierite,

said body having a coefficient of thermal expansion of no greater than $4 \times 10^{-7} \cdot ^\circ\text{C}^{-1}$, from 25°C to 800°C, and a total porosity of greater than 42% by volume.
2. A method of claim 1 wherein the BET surface area of said talc is no greater than 3 m²/g, and/or said talc has a morphology index of no less than 0.80, and/or said talc has a CaO level of no greater than 0.3% by weight.
3. A method of claim 1 or 2 wherein the BET surface area of said clay is no less than 7 m²/g based on said clay in the uncalcined state.

4. A method of claim 1 or 2 wherein said clay is selected from the group consisting of kaolin clay, calcined clay, and combinations thereof, wherein when calcined clay is used as at least part of said clay, the percent mullite present in said calcined clay is no less than 2% by weight.
5. A method of claim 1, 2, 3 or 4 wherein said clay is present in said raw materials at no greater than 20% by weight.
6. A method of claim 1, 2, 3, 4 or 5 wherein said aluminum oxide yielding component is selected from the group consisting of aluminum oxide, aluminum hydroxide, aluminum oxyhydrate and combinations thereof.
7. A method of claim 6 wherein aluminum hydroxide makes up no less than 1% by weight of said raw materials.
8. A method of any one of claims 1-7 wherein said composition consists essentially of nominally in percent by weight 12 to 16 magnesium oxide, 33 to 38 aluminum oxide, and 49 to 54 silica.
9. A method of any one of claims 1-8 wherein said burnout agent is elemental carbon, or is graphite, and/or wherein said graphite has a BET surface area of no greater than 5 m²/g.
10. Method of any one of claims 1-9 wherein said firing is done by heating said green body to a first temperature of 1100 °C to 1150 °C, and thereafter from said first temperature to a second temperature of 1300 °C to 1350 °C at a firing rate of 5 °C per hour to 100 °C per hour, and thereafter to a third temperature of at least 1390 °C and holding at said third temperature for 6 hours to 16 hours.
11. Method of claim 10 wherein said firing rate is 20 °C per hour to 60 °C per hour, and/or said third temperature is 1400 °C to 1410 °C.
12. Method of any one of the preceding claims, wherein said coefficient of thermal expansion is no greater than $2 \times 10^{-7} \text{ }^{\circ}\text{C}^{-1}$, from 25 °C to about 800 °C.
13. Method of any one of the preceding claims, wherein said total porosity of said cordierite body is 42% to 60%.
14. Method of any one of the preceding claims, wherein said body has a median pore diameter of 5 to 40 micrometers, and/or wherein in 30% to 100% of the total porosity of said body, the pore diameter is greater than 10 micrometers.
15. Method of any one of the preceding claims, wherein said body has a honeycomb structure.
16. Method of any one of the preceding claims, wherein said body has a cordierite content of at least 97% by weight.

Patentansprüche

1. Verfahren zur Herstellung eines Cordierit-Körpers, umfassend:
 - a) Auswählen von Rohmaterialien zur Herstellung einer Zusammensetzung, die beim Brennen Cordierit bildet, wobei sich die Rohmaterialien wie folgt zusammensetzen:
Talkum mit einer BET-Oberfläche von nicht mehr als 5 m²/g,
0 bis 48 Gew.-% Ton, wobei der Ton aus plättchenförmigem Ton, geschichtetem Ton, der während der Verarbeitung zu Plättchen delaminierbar ist, und Mischungen hiervon ausgewählt wird, einem Aluminiumoxid ergebenden Bestandteil mit einer mittleren Teilchengröße, ausgewählt aus der Gruppe von 3 bis 8 µm im Durchmesser, und nicht mehr als 3 µm im Durchmesser, und freiem Siliciumdioxid,
 - b) inniges Vermischen der Rohmaterialien mit einer wirksamen Menge an Träger und Formgebungshilfsmitteln, um den Rohmaterialien eine plastische Formbarkeit und eine grüne Festigkeit zu verleihen und hieraus eine plastische Mischung zu bilden, und mit einem Ausbrennmittel, wenn die mittlere Teilchengröße des Aluminiumoxid ergebenden Bestandteils nicht mehr als 3 µm im

- Durchmesser beträgt;
 c) Formen der Rohmaterialien zu einem grünen Körper;
 d) Trocknen des grünen Körpers; und
 e) Erhitzen des grünen Körpers bei einer ausreichenden Temperatur für einen ausreichenden Zeitraum zur Ausbildung eines Cordierit-Körpers, wobei der Cordierit-Körper wenigstens 93 Gew.-% Cordierit aufweist,
 der Körper einen Wärmeausdehnungskoeffizienten von nicht mehr als $4 \times 10^{-7}/^{\circ}\text{C}$ von 25°C bis 800°C und eine Gesamtporosität von mehr als 42 Vol.-% aufweist.
2. Verfahren nach Anspruch 1, worin die BET-Oberfläche des Talkums nicht mehr als $3 \text{ m}^2/\text{g}$ und/oder das Talkum einen Morphologie-Index von nicht weniger als 0,80 und/oder das Talkum einen CaO-Gehalt von nicht mehr als 0,3 Gew.-% aufweist.
 3. Verfahren nach Anspruch 1 oder 2, worin die BET-Oberfläche des Tons nicht weniger als $7 \text{ m}^2/\text{g}$, bezogen auf den Ton im uncalcinierten Zustand, beträgt.
 4. Verfahren nach Anspruch 1 oder 2, worin der Ton aus der Gruppe von Kaolinton, calciniertem Ton und Kombinationen hiervon ausgewählt wird, worin der Prozentsatz an im calcinierten Ton vorliegenden Mullit nicht weniger als 2 Gew.-% beträgt, wenn calcinierter Ton als wenigstens ein Teil des Tons verwendet wird.
 5. Verfahren nach Anspruch 1, 2, 3 oder 4, worin der in den Rohmaterialien vorhandene Ton in einer Menge von nicht mehr als 20 Gew.-% vorliegt.
 6. Verfahren nach Anspruch 1, 2, 3, 4 oder 5, worin der Aluminiumoxid ergebende Bestandteil aus Aluminiumoxid, Aluminiumhydroxid, Aluminiumoxyhydrat und Kombinationen hiervon ausgewählt wird.
 7. Verfahren nach Anspruch 6, worin Aluminiumhydroxid nicht weniger als 1 Gew.-% der Rohmaterialien ausmacht.
 8. Verfahren nach einem der Ansprüche 1-7, wobei die Zusammensetzung im wesentlichen aus, nominell in Gew.-%, 12 bis 16 Magnesiumoxid, 33 bis 38 Aluminiumoxid und 49 bis 54 Siliciumdioxid besteht.
 9. Verfahren nach einem der Ansprüche 1-8, worin das Ausbrennmittel elementarer Kohlenstoff oder Graphit ist und/oder worin das Graphit eine BET-Oberfläche von nicht mehr als $5 \text{ m}^2/\text{g}$ aufweist.
 10. Verfahren nach einem der Ansprüche 1-9, worin das Brennen durch Erhitzen des grünen Körpers auf eine erste Temperatur von 1100°C bis 1150°C und anschließend von dieser ersten Temperatur auf eine zweite Temperatur von 1300°C bis 1350°C mit einer Brenngeschwindigkeit von $5^{\circ}\text{C}/\text{Stunde}$ bis $100^{\circ}\text{C}/\text{Stunde}$ und anschließend auf eine dritte Temperatur von wenigstens 1390°C und Beibehalten dieser dritten Temperatur für 6 bis 16 Stunden durchgeführt wird.
 11. Verfahren nach Anspruch 10, worin die Brenngeschwindigkeit $20^{\circ}\text{C}/\text{Stunde}$ bis $60^{\circ}\text{C}/\text{Stunde}$ und/oder die dritte Temperatur 1400°C bis 1410°C beträgt.
 12. Verfahren nach einem der vorhergehenden Ansprüche, worin der Wärmeausdehnungskoeffizient nicht mehr als $2 \times 10^{-7}/^{\circ}\text{C}$ von 25°C bis etwa 800°C beträgt.
 13. Verfahren nach einem der vorhergehenden Ansprüche, wobei die Gesamtporosität des Cordieritkörpers 42% bis 60% beträgt.
 14. Verfahren nach einem der vorhergehenden Ansprüche, wobei der Körper einen mittleren Porendurchmesser von 5 bis $40 \mu\text{m}$ aufweist und/oder worin in 30% bis 100% der Gesamtporosität des Körpers der Porendurchmesser mehr als $10 \mu\text{m}$ beträgt.
 15. Verfahren nach einem der vorhergehenden Ansprüche, worin der Körper eine wabenförmige Struktur aufweist.

16. Verfahren nach einem der vorhergehenden Ansprüche, worin der Körper einen Cordierit-Gehalt von wenigstens 97 Gew.-% aufweist.

Revendications

5

1. Procédé de production d'un corps en cordiérite, ledit procédé comprenant:

a) une sélection de matières premières pour former une composition donnant de la cordiérite par cuisson, lesdites matières premières étant composées de:

talc présentant une aire de surface B.E.T. qui n'est pas supérieure à 5 m²/g,

10

0 à 48% en poids d'argile, ladite argile étant choisie dans le groupe comprenant l'argile en plaquettes, l'argile en blocs qui peut être délaminiée en plaquettes pendant le traitement, et des mélanges de celles-ci,

15

un composant donnant de l'oxyde d'aluminium ayant une dimension moyenne de particules choisie dans le groupe constitué de diamètres de 3 à 8 micromètres, et de diamètres qui ne sont pas supérieurs à 3 micromètres, et

de la silice libre,

20

b) un mélange intime desdites matières premières avec une quantité efficace d'agents vecteurs et de conformation pour conférer une formabilité plastique et une résistance du vert auxdites matières premières et former un mélange plastique de celles-ci, et avec un agent d'échauffement lorsque ladite dimension moyenne de particules dudit composant donnant de l'oxyde d'aluminium n'a pas un diamètre supérieur à 3 micromètres environ;

c) une transformation desdites matières premières en un corps vert;

d) un séchage dudit corps vert; et

25

e) un chauffage dudit corps vert à une température suffisante pendant une durée suffisante pour former un corps en cordiérite, dans lequel le corps en cordiérite comprend au moins 93% en poids de cordiérite,

ledit corps ayant un coefficient de dilatation thermique qui n'est pas supérieur à $4 \times 10^{-7} \text{ } ^\circ\text{C}^{-1}$, de 25 °C à 800 °C, et une porosité totale supérieure à 42% en volume.

30

2. Procédé selon la revendication 1, dans lequel l'aire de surface B.E.T. dudit talc n'est pas supérieure à 3 m²/g et/ou ledit talc a un indice de morphologie qui n'est pas inférieur à 0,80 et/ou ledit talc a un niveau de CaO qui n'est pas supérieur à 0,3% en poids.

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3. Procédé selon l'une quelconque des revendications 1 ou 2, dans lequel l'aire de surface B.E.T. de ladite argile n'est pas inférieure à 7 m²/g en se basant sur ladite argile à l'état non calciné.

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4. Procédé selon l'une quelconque des revendications 1 ou 2, dans lequel ladite argile est choisie dans le groupe constitué par l'argile de kaolin, l'argile calcinée et des combinaisons de celles-ci, dans lequel, lorsque l'argile calcinée est utilisée en tant qu'au moins une partie de ladite argile, le pourcentage de mullite présente dans ladite argile calcinée n'est pas inférieure à 2 % en poids.

45

5. Procédé selon l'une quelconque des revendications 1, 2, 3 ou 4, dans lequel ladite argile est présente dans lesdites matières premières avec une teneur qui n'est pas supérieure à 20 % en poids.

6. Procédé selon l'une quelconque des revendications 1, 2, 3, 4 ou 5, dans lequel ledit composant donnant de l'oxyde d'aluminium est choisi dans le groupe constitué par l'oxyde d'aluminium, l'hydroxyde d'aluminium, l'oxyhydrate d'aluminium et des combinaisons de ceux-ci.

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7. Procédé selon la revendication 6, dans lequel l'hydroxyde d'aluminium ne forme pas plus de 1 % en poids desdites matières premières.

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8. Procédé selon l'une quelconque des revendications 1 à 7, dans lequel ladite composition est essentiellement constituée, de manière nominale en pourcentage en poids, de 12 à 16 en oxyde de magnésium, 33 à 38 en oxyde d'aluminium et 49 à 54 en silice.

9. Procédé selon l'une quelconque des revendications 1 à 8, dans lequel ledit agent d'échauffement est du carbone élémentaire ou du graphite et/ou dans lequel ledit graphite présente une aire de surface B.E.T. qui n'est pas supérieure à 5 m²/g.

10. Procédé selon l'une quelconque des revendications 1 à 9, dans lequel ladite cuisson est réalisée par chauffage dudit corps vert à une première température de 1100 °C à 1150 °C et, ensuite, de ladite première température à une seconde température de 1300 °C à 1350 °C avec une vitesse de cuisson de 5 °C par heure à 100 °C par heure et, ensuite, à une troisième température d'au moins 1390 °C, et le maintien à ladite troisième température pendant une durée de 6 à 16 heures.
11. Procédé selon la revendication 10, dans lequel ladite vitesse de cuisson est de 20 °C par heure à 60 °C par heure et/ou ladite troisième température est de 1400 °C à 1410 °C.
12. Procédé selon l'une quelconque des revendications précédentes, dans lequel ledit coefficient de dilatation thermique n'est pas supérieur à $2 \times 10^{-7} \text{ }^{\circ}\text{C}^{-1}$ de 25 °C à environ 800 °C.
13. Procédé selon l'une quelconque des revendications précédentes, dans lequel ladite porosité totale dudit corps en cordiérite est de 42 % à 60 %.
14. Procédé selon l'une quelconque des revendications précédentes, dans lequel ledit corps présente un diamètre moyen de pores de 5 à 40 micromètres et/ou dans lequel dans 30 % à 100 % de la porosité totale dudit corps, le diamètre de pore est supérieur à 10 micromètres.
15. Procédé selon l'une quelconque des revendications précédentes, dans lequel ledit corps présente une structure en nid d'abeilles.
16. Procédé selon l'une quelconque des revendications précédentes, dans lequel ledit corps présente une teneur en cordiérite d'au moins 97 % en poids.

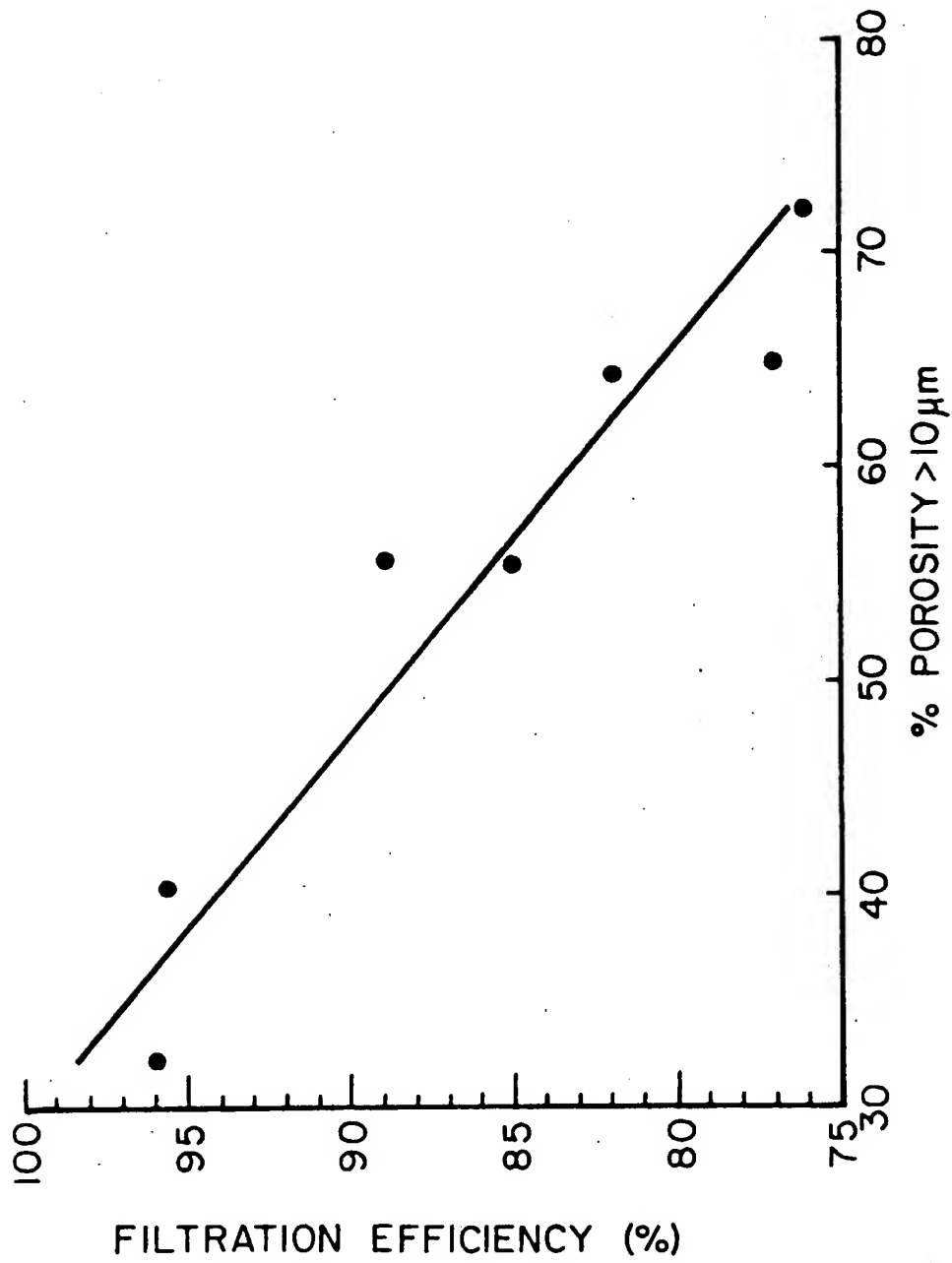


Fig. 1

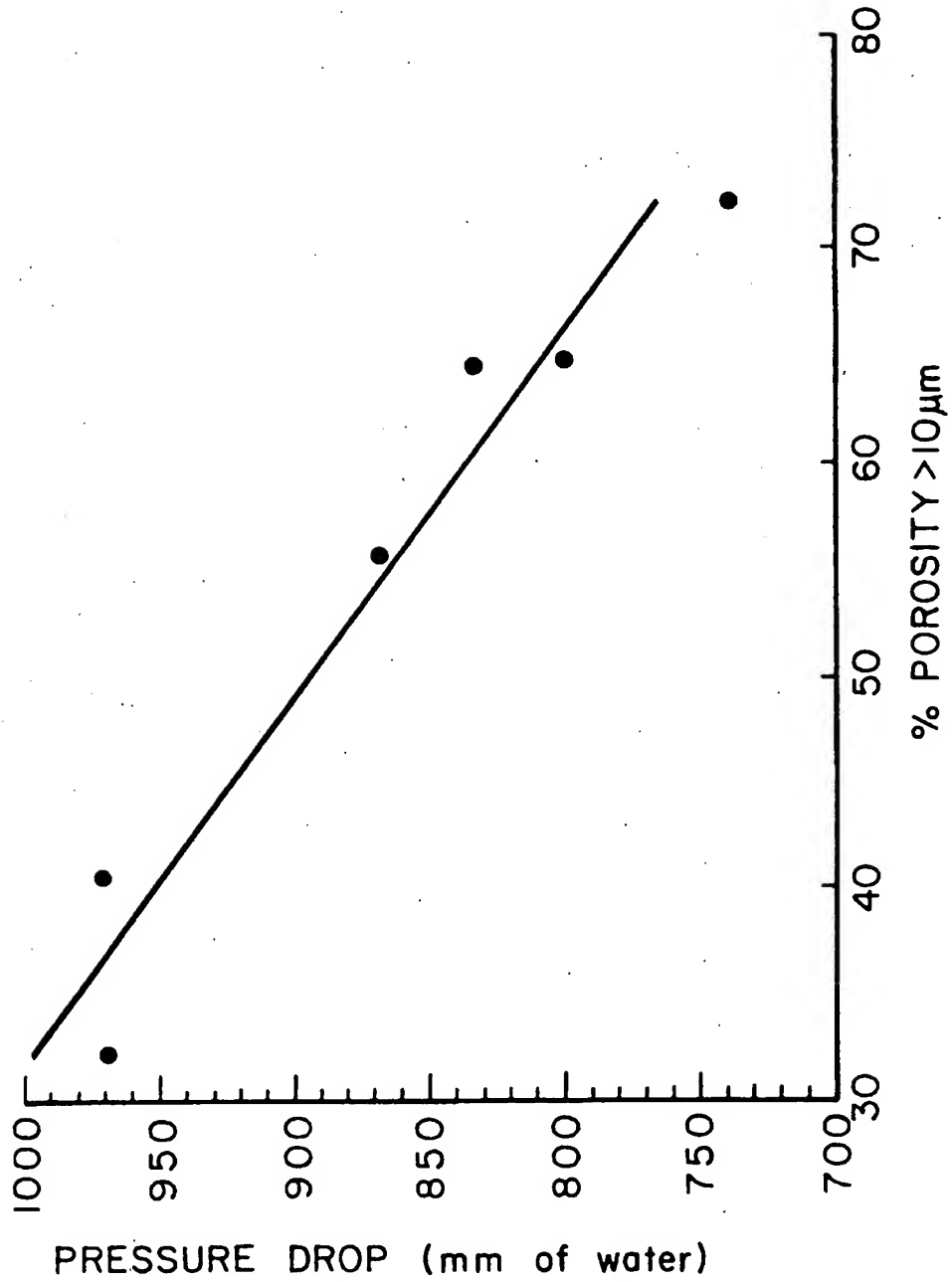


Fig. 2